

# APPARATUS FOR COUPLING A FIBER OPTIC CABLE TO AN OPTOELECTRONIC DEVICE, A SYSTEM INCLUDING THE APPARATUS, AND A METHOD OF FORMING THE SAME

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## RELATED APPLICATIONS

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This application claims the benefit of provisional application serial no. 60/270,387, entitled APPARATUS FOR COUPLING A FIBER OPTIC CABLE TO A MICROELECTRONIC DEVICE, A SYSTEM STRUCTURE INCLUDING THE APPARATUS, AND A METHOD OF FORMING THE SAME in the name of Golwalker et al., filed February 21, 2001 and provisional application serial no. 60/276,296, entitled APPARATUS FOR COUPLING A FIBER OPTIC CABLE TO A MICROELECTRONIC DEVICE USING A FUSED FIBER FACEPLATE, A SYSTEM INCLUDING THE APPARATUS, AND A METHOD OF FORMING THE SAME, in the name of Davis et al., filed March 16, 2001.

## FIELD OF THE INVENTION

The present invention generally relates to optoelectronic devices. More particularly, the invention relates to apparatus for coupling optical fibers to optoelectronic devices, systems including the apparatus and optoelectronic components, and methods of forming the apparatus and system.

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## BACKGROUND OF THE INVENTION

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Fiber optic systems are often used to transmit information such as voice band and data across a network. Such systems include a light transmitting device (e.g., a laser) coupled to a first end of a fiber cable and a light receiving device (e.g., a photodetector) coupled to the other end of the cable; the light emitting and light receiving devices are collectively referred to as optoelectronic devices. In addition, the fiber optic system may also include an optical coupler to increase the efficiency of light transfer between the optoelectronic device and the fiber cable.

Various prior-art techniques and couplers have been developed to optically connect the fiber cable to an optoelectronic device. For example, couplers, including lenses to focus light emitted from a laser toward a fiber cable or from the cable toward a detector have been developed. Such systems generally require – precise alignment of the optoelectronic device, the coupler, and the cable to achieve high-efficiency light transfer. The precision alignment techniques are typically manual, time consuming and expensive. Thus, improved optical couplers, which do not require or require less manual alignment between various components of the fiber optic system are desired.

An additional problem associated with traditional optical couplers is that the couplers typically do not account for electrical connections between the optoelectric device and substrate such as a printed circuit board. Instead, the electrical connections are generally formed by attaching the optoelectric device to a flexible substrate, which is in turn attached to the printed circuit board. With the prior art coupler, the flexible substrate allows the optoelectronic device to be manually aligned with the coupler to increase transmission efficiency. However, the use of the flexible substrate may add undesired cost to and require additional space for the fiber optic system. Accordingly, improved optical couplers that facilitate electrical connection between an optoelectric device and a substrate are desired.

### **SUMMARY OF THE INVENTION**

The present invention provides an improved connector or coupler for linking optical fibers to microelectronic devices, a system including the coupler, and a method of forming the coupler and system. The way in which the present invention addresses various drawbacks of the now-known fiber optical couplers and connector systems will be addressed in greater detail below. However, in general, the fiber optic cable connector and system of the present invention allow for relatively easy and inexpensive coupling of an optoelectronic device to an optical fiber.

In accordance with one embodiment of the invention, an optical coupler includes a light transmission path and at least one alignment groove configured to facilitate alignment between and coupling of a fiber cable ribbon and the optical coupler. In accordance with one aspect of this embodiment, the coupler includes electrical connectors that provide a conductive path between an optoelectronic device attached to the coupler and a substrate such as a printed circuit board. In accordance with a further aspect of this embodiment, the light transmission path is

formed of a bundle of optical fibers, wherein the core diameter of each of the fibers is less than the core diameter of the optical fibers of the fiber ribbon. In accordance with a further aspect, the coupler includes an encapsulant surrounding at least a portion of the grooves, the transmission path, and the connectors.

5 In accordance with a further embodiment of the invention, an optical coupler includes a microelectronic substrate, including multiple layers of conductive paths or traces formed therein, at least one alignment groove or sleeve, an optical path, and an encapsulant.

10 In accordance with another embodiment of the invention, an optoelectronic system includes an optical coupler, an optoelectronic device, and an optical fiber. The optoelectronic device may be a light emitting (e.g., a laser) or light receiving (e.g., a photodiode) device. In accordance with one aspect of this embodiment, the optical coupler includes electrical connectors and at least one of the optoelectronic devices is electrically coupled to the electrical connectors. In accordance with a further aspect of the invention, the optical coupler includes guides, and the optical fiber forms part of a fiber ribbon connector that includes guide pins configured to be received by the guides of the optical coupler, such that when the fiber ribbon is attached to the optical coupler, the transmission path of the optical coupler is aligned with the optical fiber(s) of the fiber ribbon. In accordance with yet a further aspect of this embodiment, the system includes a gel compound attached to the optoelectronic device and the optical coupler between the optoelectronic device and the optical coupler and/or to increase light transfer between the optical coupler and the optoelectronic device.

20 In accordance with another embodiment of the invention, a method of forming an optical coupler includes forming electrical connectors from a plate of conductive material, forming guides, attaching an optical transmission medium to a portion of the electrical connectors, encapsulating the transmission medium and at least a portion of the electrical connectors, and polishing at least one surface of the transmission medium. In accordance with one aspect of this embodiment, the guides are formed from the plate of conductive material.

25 In accordance with yet another embodiment of the invention, a method of forming an optical coupler includes forming a microelectronic substrate having electrical interconnections, attaching an optical transmission medium and guides to the microelectronic substrate, 30 encapsulating the guides and the transmission medium, and polishing at least one surface of the transmission medium.

1 In accordance with another embodiment of the invention, a method of forming an optical  
coupler includes forming electrical connectors from a plate of conductive material, attaching an  
optical transmission medium, which includes optical elements configured to collimate and  
refocus light, and encapsulating at least a portion of the transmission medium. In accordance  
5 with one aspect of this embodiment, the optical elements include of a pair of micro-optical relay  
lens arrays which are diffractive, refractive or holographic lenses.

10 In accordance with a further embodiment of the invention, a method of forming an optical  
interconnect system includes forming an optical coupler, attaching an optoelectronic device to  
the coupler, and attaching a fiber optic ribbon to the coupler. In accordance with one aspect of  
this embodiment, the fiber ribbon is removeably attached to the coupler. In accordance with a  
further aspect of this embodiment, the optoelectronic component is attached to the coupler using  
solder bump technology, surface mount technology, anisotropic conductive film (ACF), and/or  
electrical adhesive or metal-metal contact technology.

15 In accordance with another embodiment of the invention, a method of forming an optical  
coupler includes forming electrical connectors from a plate of conductive material, attaching an  
optical transmission medium that is transparent in the region of the radiation spectrum including  
the visible and the visible to mid infrared wavelengths, and encapsulating at least a portion of the  
transmission medium.

20 In accordance with one or more of the embodiments of the present invention, the optical  
transmission path is coated with anti-reflection material to minimize reflection losses as light  
travels through the path.

### **BRIEF DESCRIPTION OF THE DRAWINGS**

25 The present invention is illustrated by way of example and not limitation in the  
accompanying figures, in which like references indicate similar elements, and in which:

FIG. 1 is a cross-sectional illustration of a portion of an optical interconnect system in  
accordance with the present invention;

FIG. 2 is a bottom perspective view of an optical coupler in accordance with one  
embodiment of the present invention;

30 FIGS. 3-5 are cross-sectional illustrations of a portion of an optical coupler in connection  
with another embodiment of the invention;

FIG. 6 is a cross-sectional illustration of an optical interconnect system in accordance with another embodiment of the invention;

FIG. 7 is a schematic illustration of a process for forming an optical coupler in accordance with the present invention;

5 FIG. 8 is a top view illustration of a conductive plate used to form connectors in accordance with the present invention;

FIGS. 9-10 are perspective illustrations of a portion of a conductive plate used to form connectors in accordance with another embodiment of the invention;

10 FIGS. 11-13 illustrate portions of an optical coupler during manufacture of the coupler in accordance with an exemplary embodiment of the invention;

FIG. 14 illustrates a portion of a substrate including electrical connectors in accordance with an exemplary embodiment of the present invention; and

FIGS. 15-16 illustrate steps of forming an optical interconnect system in accordance with the present invention.

Skilled artisans will appreciate that elements in the figures are illustrated for simplicity and clarity and have not necessarily been drawn to scale. For example, the dimensions of some of the elements in the figures may be exaggerated relative to other elements to help to improve understanding of embodiments of the present invention.

### **DETAILED DESCRIPTION OF EXEMPLARY EMBODIMENTS**

20 FIG. 1 illustrates a cross-sectional side view of an optical interconnect system 100 in accordance with the present invention. System 100 includes an optical coupler 102, a fiber ribbon 104, and an optoelectronic device 106. System 100 may also include a driver 108 to drive  
25 optoelectronic device 106, a substrate 110 such as a printed circuit board or the like, and a gel 111 to facilitate efficient light transfer between device 103 and coupler 102 and to protect a portion of device 102 and coupler 102 from the environment. Although system 100 is illustrated as including a fiber ribbon 104, a system in accordance with the present invention may include a coupler coupled to an optoelectronic device on one side and any suitable waveguide, optical  
30 device, photonics devices, or the like on the other side. In accordance with one embodiment of

the invention, a transceiver includes a portion of system 100. In particular, the transceiver includes optoelectronic device 106 and coupler 102.

Coupler 102, illustrated in perspective view in FIG. 2., is configured to facilitate forming an optical connection between an optical fiber of ribbon 104 and optoelectronic device 106, without requiring extensive, labor intensive adjustment of optoelectronic component 106 or fiber ribbon 104. In other words, coupler 102 is designed to provide a "self-aligned" optical path between optoelectronic component 106 and fiber ribbon 104. In addition, in accordance with various embodiments of the invention, coupler 102 also provides an electrical connection between optoelectronic component 106 and a substrate 110. In accordance with the illustrated embodiment, coupler 102 includes an optical medium 112, electrical connectors 114, guides 116 and 118, and an encapsulant 120.

Optical transmission medium 112 may be formed of any material that is transparent in the light wavelengths transferred between device 106 and fibers of ribbon 104. For example, medium 112 may be formed of a glass block, a fiber ribbon, a fiber tape, a holographic optical element, a cavity formed within encapsulant 120, a ferrule or any other suitable waveguide material or optical bus. In accordance with one embodiment of the invention, medium 112 includes a bundle of fused glass fibers, wherein each of the fibers has a core diameter that is less than the core diameter of a fiber of ribbon 104. For example, when the fibers of ribbon 104 have a core diameter of about 50 micrometers ( $\mu\text{m}$ ), the diameter of the fused fibers of medium 112 are preferably about 4  $\mu\text{m}$  to about 10  $\mu\text{m}$ . In accordance with another embodiment of the invention, medium 112 comprises optical elements configured to collimate and refocus light. Such optical elements are well suited for forming multiplexing and demultiplexing couplers.

Forming the transmission medium of fused fibers is advantageous because each fiber transmits light directly from one end of the fiber to the other, without dispersion of light. Thus, multiple optoelectronic devices 106 can be coupled to a single fused-fiber transmission medium and transmit or receive light to or from the medium, without interference from the light transmission of neighboring optoelectronic devices or fibers of ribbon 104. Furthermore, because the diameter of the individual fused fibers is less than the core diameter of a fiber of ribbon 104, it is relatively easy to assemble system 100, such that an optical path between optoelectronic device 106 and the fiber of ribbon 104 is in alignment. For example, such a scheme enables the coupling of light between optoelectronic devices and receivers or detectors.

5 The dimensions of transmission medium 112 may vary from application to application and depend on such factors as the configuration of the optoelectronic device, the composition of the transmission medium and the like. However, in accordance with one embodiment of the invention, medium 112 includes fused fibers and has overall dimensions of about 3.1 mm wide, about 450 micron high, and about 2 mm long (along the length of the fused fibers).

10 When used, electrical connectors 114 provide a conductive path between optoelectronic device 106 and substrate 110 to form a conductive path between, for example, driver 108 and optoelectronic device 106. As explained in greater detail below, connectors 114 may be formed from a sheet or plate of conductive material by patterning and forming or bending the conductive material, from wire bonds, or from a microelectronic substrate having conductive layers formed therein, to eventually form a conductive path with an effective ninety degree electrical bend. The effective ninety degree electrical bend is advantageous because several optoelectronic devices such as vertical cavity surface emitting lasers (VCSELs) emit light in the direction of the surface upon which electrical contacts of the device are formed. With several prior art optoelectronic coupler systems, the VCSEL is bonded directly to the substrate and the light is bent ninety degrees using relatively complicated and expensive optical couplers.

20 Electrical connectors are generally configured such that when optoelectronic device 106 is coupled to coupler 102, the light output or input section of device 106 is aligned with medium 112 and to a desired fiber of ribbon 104. Therefore, the spacing and dimensions of coupler 114 is often determined by the optoelectronic devices attached to the connectors. In accordance with one embodiment of the invention, connectors 114 are formed of a conductive metal plate (e.g., copper) having a thickness of about 70  $\mu\text{m}$  and are spaced about 125  $\mu\text{m}$  apart. Couplers 114 may also include additional material such as gold to facilitate bonding to optoelectronic device 106 and solder material to facilitate bonding to substrate 110.

25 Guides 116 and 118 are generally configured to facilitate alignment between coupler 102 and fiber ribbon 104. In particular, guides 116 and 118 are designed to receive pins or protrusions from ribbon 104, such that the fibers of ribbon 104 align with medium 112 and to optoelectronic devices 106. In accordance with one embodiment of the invention, ribbon 104 includes guide pins as are typically found on MT series of fiber connectors 122, and guides 116 and 118 are formed of tubes 124 and 126, which eventually form cavity regions within encapsulant 120. Tubes 124 and 126 may be formed of any suitable material. For example,

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tubes 124 and 126 may be formed of molded plastic or conductive material used to form couplers 114.

Encapsulant 120 is generally configured to provide insulation between couplers or connectors 114 and to provide a protective environment around medium 112 and at least a portion of connectors 114. Exemplary encapsulant 120 materials include transfer mold compound, ceramic material, and other suitable materials. In accordance with one embodiment of the invention, encapsulant 120 is formed of silica-filled epoxy. In accordance with another embodiment, encapsulant 120 includes Glob Top.

Gel 111 may include any suitable optically transparent material. In accordance with one embodiment of the invention, gel 111 includes a clear organic material having an index of refraction that is "index matched" to the index of refraction of transmission medium 112 and to a portion of the optoelectronic device. In this context, "indexed matched" means that the index of refraction of material 111 is the same as the index of refraction of either transmission medium 112 or a portion of the optoelectronic device, or the index refraction of gel 111 is between the index of refraction of the transmission medium 112 and a portion of the optoelectronic device.

Optoelectronic or photonics device 106 may include any suitable light emitting or light detecting device. For example, device 106 may include light emitting device such as a light emitting diode, an edge emitting laser, a VCSEL, a distributed feedback laser, a distributed Bragg reflective light source, or the like. The light emitting device may emit light of one or more wavelengths. If device 106 is a light detecting device, device 106 may include a photo detector such as reversed-biased pn junction diodes, p-i-n diode, metal-semiconductor-metal (MSM) detector, a resonant cavity enhanced detector, a liquid crystal display, or the like. Devices 106 may be a discrete component or assembled in a one dimensional (1-D) or two-dimensional (2-D) array. Furthermore, device 106 may be configured to emit or detect light of any desired wavelength; however, device 106 is preferable designed to emit or detect light of one or more wavelengths in the mid infrared to and including the visible radiation spectrum.

Substrate 110 may include any suitable material. Exemplary substrate materials include FR-4 printed circuit board materials, ceramic materials, flexible substrates, silicon, and the like.

FIGS. 3-5 illustrate cross-sectional views of connectors 300, 400, and 500 in accordance with additional embodiments of the invention. Any of coupler 300-500 may suitably replace coupler 102 of system 100. As explained in greater detail below, each of couplers 300, 400, and



500 includes a microelectronic substrate 302 to form a conductive path between an optoelectronic component 106 and a substrate 110, alignment grooves 304, a transmission medium as described above, and an encapsulant (not illustrated in FIGS. 3-5).

Microelectronic substrate 302 includes conductive plugs or filled vias 304 and may additionally include conductive traces, which interconnect various portions of substrate 302. Substrate 302 may include only a single layer of conductive plugs 306, as illustrated in FIG. 3, or substrate 302 may include multiple rows of conductive plugs as illustrated in FIG. 5. Use of multiple conductive plugs on a surface of the coupler may be advantageous because it provides greater surface area to which optoelectronic devices can be attached. Thus, multiple, stacked vias can be used to provide flexibility of use of substrate 302, such that a variety of optoelectronic devices, having a variety of electrode spacing, can be attached to substrate 302. Alternatively, substrate 302 may only include conductive traces on a surface to which device 106 is attached. In this case, electrodes of device 106 are coupled directly to the conductive traces, which are in turn coupled to the substrate using distal conductive plugs.

In accordance with one embodiment of the invention, substrate 302 includes ceramic material having metallic (e.g., copper) traces and conductive plugs formed therein. However, other suitable insulating materials such as low dielectric constant organic materials and conducting material such as tungsten paste may be used to form substrate 302.

Grooves 304 and the transmission medium may include any of the materials described above in connection with FIGS. 1 and 2. For example, transmission medium 308 may include fused fibers as illustrated in FIGS. 3 and 5, individual fibers 402 as illustrated in FIG. 4, a glass block, a hologram, or the like.

Coupler 300, 400, and 500 may also include solder bumps to facilitate electrical and mechanical attachment of couplers 300, 400, and 500 to a substrate. For example, lead-tin alloy bumps may be formed on a bottom surface of substrate 302 using known solder bump technology.

FIG. 6 illustrates a system 600 in accordance with yet another embodiment of the invention. System 600 is similar to system 100, except system 600 uses a flexible substrate 602 (e.g., flex tape) to form an electrical contact between optoelectronic device 108 and another device such as driver 108. Although illustrated as having flexible substrate bent underneath

device 106, substrate 602 may suitably bend in another direction, such that, e.g., substrate 602 lies underneath coupler 102.

FIG. 7 illustrates a method 700 for forming a coupler, such as coupler 102, in accordance with the present invention. Method 700 includes the steps of forming electrical connectors and guides 702, forming transmission path 704, encapsulating the transmission path and at least a portion of the connectors 706, singulating the couplers 708, polishing the ends of the transmission medium (optional) 710, and plating the ends of the leads with material 712 to facilitate coupling of the coupler to an optoelectronic device and/or a substrate. A method of forming a system in accordance with the invention additionally includes the steps of attaching an optoelectronics device to a coupler and placing index matching gel between the optoelectronic device and a transmission path of the coupler.

In accordance with one embodiment of the invention, step 702 includes forming electrical connectors (e.g., connectors 114) and guides (e.g., guides 116 and 118) from a plate or sheet of conductive material. FIG. 8 illustrates a top view of a patterned sheet of conductive material 800, such as copper, having a thickness of about 70  $\mu\text{m}$  suitable for forming connectors in accordance with the present invention. The sheet may be patterned using, for example, photoresist and etched, or alternatively, be cut to form the desired pattern. In accordance with the illustrated embodiment, patterned sheet 800 includes lead portions 802, which can be used to form electrical connections between the optoelectronic device and a substrate and sleeve portions 804, which can be bent and shaped to form groove spacers 124, illustrated in FIG. 2. Additionally, plate 800 may be etched or cut to form a common ground plane region 806.

FIG. 9 illustrates another conductive plate 900 in accordance with an alternate embodiment of the invention, plate 900. Plate 900 is similar to plate 800, except that plate 900 does not include regions to form groove spacers. Instead, plate 900 includes leads 902 and groove regions 904, onto which groove sleeves will be attached.

After plate 900 is patterned, the leads are bent to form structure 1000 illustrated in FIG. 10. The leads may be bent in any desired fashion, but are preferably bent such that the leads form an electrical connection with an effective ninety degree turn. In accordance with one aspect of this embodiment, the effective ninety degree turn is obtained by forming two 135° bends in the leads, as best illustrated in FIG. 1. Structure 800 may similarly be formed to bend leads 802 and form the groove sleeves.

Once the leads are bent and the groove sleeves 1102 are formed and/or attached to the frame, transmission medium or spacer 1104 is attached to the frame of conductive material to form structure 1100, as illustrated in FIG. 11. The transmission medium may be attached to frame 1000 in any suitable manner—for example, an epoxy or other suitable glue may be used to attach the medium or a spacer for the medium to frame 1000.

Next, during step 706, an encapsulant material 1202 is formed over structure 1100 to form structure 1200, illustrated in FIG. 12. In accordance with a preferred method of forming an optical coupler of the present invention, encapsulant 1202 includes an epoxy resin compound applied using transfer mold technology. However, other suitable encapsulating techniques may also be used in accordance with the present invention.

As illustrated in FIGS. 9-12, multiple sets of connectors and alignment grooves may be formed from a single sheet of conductive material and encapsulated at one time. In this case, individual optical coupler structures 1300, illustrated in FIG. 13, are formed during step 708 by singulating the couplers from structure 1300. Step 708 may include sawing, cutting, bending, or otherwise separating the individual structures 1300 from one another.

After structures 1300 are separated during step 708, ends of structure 1300, e.g., ends 1302 and 1304 may be polished during step 710 to provide a smooth flat surface of transmission portion 1306.

Finally, ends of the leads 1308 are plated with a material configured to facilitate coupling of the optical coupler to an optoelectronic device during step 712. For example, ends 1308 may be plated with gold or solder to facilitate flip-chip bonding between the coupler and the optoelectronic device and lead ends that attach to the substrate may be coated with gold or solder to facilitate bonding between the coupler and the substrate.

In accordance with another embodiment of the invention, electrical connector and guide formation step 702 includes forming electrical connectors using wire bond technology. In this case, connectors are formed by attaching a wire 1402 (e.g., a wire typically used in wire bonding processing having a diameter of about 2 mils) to a substrate 1404 such as silicon, encapsulating the wire with an encapsulant 1406 such as transfer mold epoxy, and severing structure 1400 along line 1408. After substrate 1400 is formed, transmission medium 1104 and guide sleeves 1102 are attached to substrate 1400 and processing continues as described above.

In accordance with yet another embodiment of the invention, as discussed above in connection with FIGS. 3-5, a microelectronic substrate having conductive interconnections can be used to form an optical coupler. In accordance with one aspect of this embodiment, substrate 302 is formed of a ceramic material such as alumina, having conductive traces and conductive plugs integrating the conductive traces formed therein. In this case, patterned indentations are formed in a top surface of the substrate (e.g., using photoresist patterning and etching techniques while the ceramic is in a green or pre-co-fire state) to form regions to attach sleeves 304 and the optical transmission medium (e.g., fused fibers 308 or fibers 402). Next alignment sleeves 308 and the optical transmission medium would be attached to substrate 302, and the structure may be exposed to an encapsulation process as described above. Then, to facilitate electrical and mechanical coupling of optical coupler 300 to a substrate, solder balls are formed on a bottom surface of structure 300. The solder balls could be formed by, for example, using a controlled collapse chip connect ("C4") solder bump formation process. As a specific example, conductive plugs 306 may be about 50  $\mu\text{m}$  in diameter and about 75  $\mu\text{m}$  in height.

In accordance with yet another embodiment of the invention, structure 300 could be formed using an organic substrate material such as FR4 or Bismaleimide Triazine (BT) epoxy, and patterned and etched using standard microelectronic substrate photolithography or laser-based methods. The remaining portion of fabricating a coupler could then proceed as previously described.

FIGS. 15 and 16 illustrate a process for forming an optical interconnect system in accordance with the present invention. After the coupler is formed, for example, using process 700 as described above, one or more optoelectronic devices is attached to an optical coupler, such as coupler 102. For example, an array of VCSELs, including, but not limited to, 2 to 12 individual VCSELs can be attached to coupler 102 using solder bump, e.g., C4 bonding techniques, a harness, an electrical adhesive, or surface mount technology. Alternately, the VCSELs may be attached to coupler 102, either individually or as an array, using other adhesive materials such as conductive tape, conductive epoxy, or the like.

After the optoelectronic devices are attached to coupler 102, fiber ribbon 104 or another suitable waveguide is attached to coupler 102 by inserting guide pins associated with and attached to ribbon 104 through grooves 116 and 118 to form system 100, illustrated in FIG. 1. As illustrated in FIG. 16, a system 1600 in accordance with the present invention may also

